

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
1 April 2004 (01.04.2004)

PCT

(10) International Publication Number
WO 2004/027392 A1

(51) International Patent Classification⁷: **G01N 3/08**

[US/US]; 19115 Prospect Ridge Lane, Houston, TX 77094
(US). **RING, Lev** [US/US]; 14126 Heatherhill Place,
Houston, TX 77077 (US).

(21) International Application Number:
PCT/US2003/025667

(22) International Filing Date: 18 August 2003 (18.08.2003)

(74) Agents: **MATTINGLY, Todd et al.**; Haynes and Boone,
LLP, Suite 4300, 1000 Louisiana Street, Houston, TX
77002-5012 (US).

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/412,653 20 September 2002 (20.09.2002) US

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,
CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH,
GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC,
LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW,
MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE,
SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ,
VC, VN, YU, ZA, ZM, ZW.

(71) Applicant (*for all designated States except US*): **ENVEN-
TURE GLOBAL TECHNOLOGY** [US/US]; 16200 A
Park Row, Houston, TX 77084 (US).

(84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),
Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

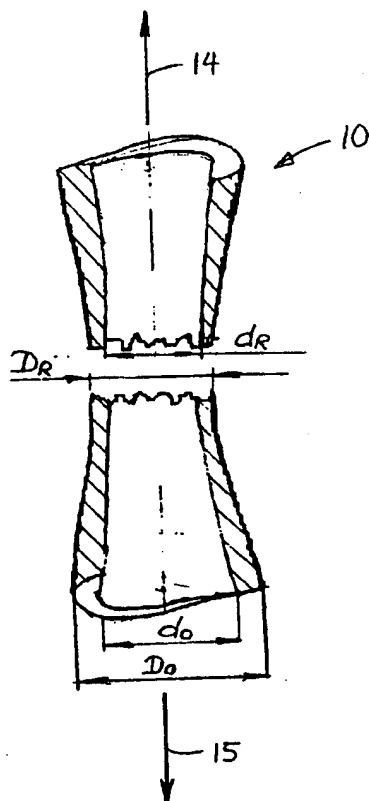
(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **SHUSTER, Mark**

[Continued on next page]

(54) Title: PIPE FORMABILITY EVALUATION FOR EXPANDABLE TUBULARS

(57) Abstract: A method of testing a tubular member (10) and selecting tubular members for suitability for expansion by subjecting a representative sample the tubular member to axial loading (14, 15), stretching at least a portion of the tubular member through elastic deformation, plastic yield and to ultimate yield, and based upon changes in length and area calculating an expandability coefficient indicative of expandability of the tubular members (10) and selecting tubular members (10) with relatively high coefficients indicative of good expandability.



WO 2004/027392 A1

BEST AVAILABLE COPY

- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

- of inventorship (Rule 4.17(iv)) for US only

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

PIPE FORMABILITY EVALUATION FOR EXPANDABLE TUBULARS

Cross Reference To Related Applications

[1] The present application claims the benefit of the filing dates of (1) U.S. provisional patent application serial no. 60/412,653, attorney docket no 25791.118, filed on 9/20/2002, the disclosure of which is incorporated herein by reference.

[2] The present application is related to the following: (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent no. 6,328,113, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (25) U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (26) U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (27) U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, (28) U.S. provisional patent application serial no. 60/3318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (29) U.S. utility

patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (30) U.S. utility patent application serial no. 10/016,467, attorney docket no. 25791.70, filed on 12/10/2001, (31) U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (32) U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/2002, (33) U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/2002, (34) U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/2002, (35) U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/2002, (36) U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/2002, (37) U.S. provisional patent application serial no. 60/394,703, attorney docket no. 25791.90, filed on 6/26/2002, (38) U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/2002, (39) U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/2002, (40) U.S. provisional patent application serial no. 60/405,610, attorney docket no. 25791.119, filed on 8/23/2002, (41) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/2002, (42) U.S. provisional patent application serial no. 60/412,542, attorney docket no. 25791.102, filed on 9/20/2002, (43) U.S. provisional patent application serial no. 60/412,487, attorney docket no. 25791.112, filed on 9/20/2002, (44) U.S. provisional patent application serial no. 60/412,488, attorney docket no. 25791.114, filed on 9/20/2002, (45) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/2002, (46) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/2002, (47) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/2002, (48) U.S. provisional patent application serial no. 60/412,196, attorney docket no. 25791.127, filed on 9/20/2002, (49) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.128, filed on 9/20/2002, and (50) U.S. provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/2002, the disclosures of which are incorporated herein by reference.

Background of the Invention

[3] The present invention relates generally to tubular steel well casing and more particularly to an expansion mandrel which reduces stress during expansion of the casing.

[4] Solid tubular casing of substantial length is used as a borehole liner in downhole drilling. The casing is comprised of end-to-end interconnected segments of steel tubing to protect against possible collapse of the borehole and to optimize well flow. The tubing often reaches substantial depths and endures substantial pressures.

[5] It is present practice to expand the steel tubing downhole by using a mandrel. This is a cold-working process which presents substantial mechanical challenges. This technology is known as solid expandable tubular (SET) technology. This cold-working process deforms the steel without any additional heat beyond what is present in the downhole environment.

[6] It is present practice to expand the steel tubing downhole by using a mandrel. This is a cold-working process which presents substantial mechanical challenges. This technology is known as solid expandable tubular (SET) technology. This cold-working process deforms the steel without any additional heat beyond what is present in the downhole environment.

[7] An expansion cone, or mandrel, is used to permanently mechanically deform the pipe. The cone is moved through the tubing by a differential hydraulic pressure across the cone itself, and/or by a direct mechanical pull or push force. The differential pressure is pumped through an inner-string connected to the cone, and the mechanical force is applied by either raising or lowering the inner string.

[8] Progress of the cone through the tubing deforms the steel beyond its elastic limit into the plastic region, while keeping stresses below ultimate yield. Expansions greater than 20%, based on pipe ID, have been accomplished. However, most applications using 4 1/4 - 13 3/8 inch tubing have required expansions less than 20%. The ID of the pipe expands to the same ID of the expansion mandrel, which is a function of expansion mandrel OD. Contact between cylindrical mandrel and pipe ID during expansion leads to significant forces due to friction. It would be beneficial to provide method for testing tubular members for suitability for the expansion process. It would also be beneficial to provide a method for selecting tubing or tubular members well suited for expansion.

Summary Of The Invention

[9] According to one aspect of the present invention, a method of testing a tubular member for suitability for expansion is provided using an expandability coefficient determined pursuant to a stress-strain test of a tubular member using axial loading.

[10] According to another aspect of the present invention, a tubular member is selected for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test of a tubular member using axial loading.

[11] According to another aspect of the present invention, a method of testing a tubular member for suitability for expansion is provided using an expandability coefficient determined pursuant to a stress-strain test using axial loading comprising calculation of plastic strain ratio for obtaining the expansion coefficient pursuant to test results and using the formula:

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}} \quad \text{Equation 1}$$

where,

f - expandability coefficient

b_o & b_k - initial and final tube area (inch²)

L_o & L_k - initial and final tube length (inch)

$b = (D^2 - d^2)/4$ - cross section tube area.

[12] According to another aspect of the present invention, a tubular member is selected for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test using axial loading comprising calculation of plastic strain ratio for obtaining the expansion coefficient pursuant to test results and using the formula:

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}} \quad \text{Equation 1}$$

where,

f - expandability coefficient

b_o & b_k - initial and final tube area (inch²)

L_o & L_k - initial and final tube length (inch)

$b = (D^2 - d^2)/4$ - cross section tube area.

[13] According to another aspect of the present invention, a tubular member is selected for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test using axial loading and one or more physical properties of the tubular member selected from stress-strain properties in one or more directional orientations of the material, Charpy V-notch impact value in one or more directional orientations of the material, stress rupture burst strength, stress rupture collapse strength, strain-hardening exponent(n -value), hardness and yield strength.

Brief Description of the Drawings

[14] Fig. 1 depicts in a schematic fragmentary cross-sectional view along a plane along and through the central axis of a tubular member that is tested to failure with axial opposed forces.

[15] Fig. 2 is a stress-strain curve representing values for stress and strain that may be plotted for solid specimen sample.

[16] Fig. 3. is a schematically depiction of a stress strain curve representing values from a test on a tubular member according to an illustrative example of one aspect of the invention.

Detailed Description of the Illustrative Embodiments

[17] One of the problems of the pipe material selection for expandable tubular application is an apparent contradiction or inconsistency between strength and elongation. To increase burst and collapse strength, material with higher yield strength is used. The higher yield strength generally corresponds to a decrease in the fracture toughness and correspondingly limits the extent of achievable expansion.

[18] It is desirable to select the steel material for the tubing by balancing steel strength with amount absorbed energy measure by Charpy testing. Generally these tests are done on samples cut from tubular members. It has been found to be beneficial to cut directional samples both longitudinally oriented

(aligned with the axis) and circumferentially oriented (generally perpendicular to the axis). This method of selecting samples is beneficial when both directional orientations are used yet does not completely evaluate possible and characteristic anisotropy throughout a tubular member. Moreover, for small diameter tubing samples representative of the circumferential direction may be difficult and sometimes impossible to obtain because of the significant curvature of the tubing.

[19] To further facilitate evaluation of a tubular member for suitability for expansion it has been found beneficial according to one aspect of the invention to consider the plastic strain ratio. One such ratio is called a Lankford value (or r-value) which is the ratio of the strains occurring in the width and thickness directions measured in a single tension test. The plastic strain ratio (r or Lankford - value) with a value of greater than 1.0 is found to be more resistant to thinning and better suited to tubular expansion. Such a Lankford value is found to be a measure of plastic anisotropy. The Lankford value (r) may be calculate by the Equation 2 below:

$$r = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}} \quad \text{Equation 2}$$

where,

r - normal anisotropy coefficient

bo & bk - initial and final width

Lo & Lk - initial and final length

[20] However, it is time consuming and labor intensive for this parameter to be measured using samples cut from real parts such as from the tubular members. The tubular members will have anisotropic characteristics due to crystallographic or "grain " orientation and mechanically induced differences such as impurities, inclusions, and voids, requiring multiple samples for reliably complete information. Moreover, with individual samples, only local characteristics are determined and the complete anisotropy of the tubular member may not be determinable. Further some of the tubular members have small diameters so that cutting samples oriented in a circumferential direction is not always possible. Information regarding the characteristics in the circumferential direction has been found to be important because the plastic deformation during expansion of the tubular members occurs to a very large extent in the circumferential direction,

[21] One aspect of the present invention comprises the development of a solution for anisotropy evaluation, including a kind of plastic strain ratio similar to the Lankford parameter that is measured using real tubular members subjected to axial loading.

[22] Fig. 1 depicts in a schematic fragmentary cross-sectional view along a plane along and through the axis 12 of a tubular member 10 that is tested with axial opposed forces 14 and 15. The tubular member 10

is axially stretched beyond the elastic limit, through yielding and to ultimate yield or fracture. Measurements of the force and the OD and ID during the process produce test data that can be used in the formula below to produce an expandability coefficient "*f*" as set forth in Equation 1 above. Alternatively a coefficient called a formability anisotropy coefficient $F(r)$ that is function of the normal anisotropy Lankford coefficient *r* may be determined as in Equation 3 below:

$$F(r) = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}} \quad \text{Equation 3}$$

$F(r)$ - formability anisotropy coefficient

b_o & b_k - initial and final tube area (inch²)

L_o & L_k - initial and final tube length (inch)

$b = (D^2 - d^2)/4$ - cross section tube area.

[23] In either circumstance *f* or $F(r)$ the use of this testing method for an entire tubular member provides useful information including anisotropic characteristics or anisotropy of the tubular member for selecting or producing beneficial tubular members for down hole expansion, similar to the use of the Lankford value for a sheet material.

[24] Just as values for stress and strain may be plotted for solid specimen samples, as schematically depicted in Fig 2, the values for conducting a test on the tubular member may also be plotted, as depicted in Fig 3. On this basis the expansion coefficient *f* (or the formability coefficient $F(r)$) may be determined. It will be the best to measure distribution (Tensile-elongation) in longitudinal and circumferential directions simultaneously.

[25] The foregoing expandability coefficient (or formability coefficient) is found to be useful in predicting good expansion results and may be further useful when used in combination with one or more other properties of a tubular member selected from stress-strain properties in one or more directional orientations of the material, strength & elongation, Charpy V-notch impact value in one or more directional orientations of the material, stress burst rupture, stress collapse rupture, yield strength, ductility, toughness, and strain-hardening exponent (*n* - value), and hardness.

[26] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

Claims

What is claimed is: -

1. A method of testing a tubular member for suitability for expansion is provided comprising the steps of subjecting at least a portion of the tubular member to axial loading, stretching at least a portion of the tubular member through the elastic deformation, plastic yield and to ultimate yield, and calculating an expandability coefficient f .
2. A method of testing a tubular member for suitability for expansion as in claim 1 wherein the step of subjecting the at least a portion of the tubular member to axial loading comprises subjecting the entire tubular member to axial loading.
3. A method of testing tubular members for suitability for expansion wherein the step of calculating an expandability coefficient comprises calculating the expandability coefficient using the following formula (Equation 1):

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{l_o b_o}} \quad \text{Equation 1}$$

where,

f - expandability coefficient

b_o & b_k - initial and final tube area (inch²)

L_o & L_k - initial and final tube length (inch)

$b = (D^2 - d^2)/4$ - cross section tube area.

4. A method of selecting tubular members for suitability for expansion is provided comprising the steps of subjecting at least a portion of a representative sample of tubular members to axial loading, stretching at least a portion of the tubular member through the elastic deformation, plastic yield and to ultimate yield, and calculating an expandability coefficient f , and choosing such tubular members for which the sample provided a desirable coefficient of expandability above a value of 1.
5. A method of selecting tubular members for suitability for expansion as in claim 1 wherein the step of subjecting the at least a portion of the tubular member to axial loading comprises subjecting at least one entire tubular member to axial loading.
6. A method of selecting tubular members for suitability for expansion wherein the step of calculating an expandability coefficient comprises calculating the expandability coefficient using the following formula (Equation 1):

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{L_o b_o}}$$

Equation 1

where,

f - expandability coefficient

b_o & b_k - initial and final tube area (inch²)

L_o & L_k - initial and final tube length (inch)

$b = (D^2 - d^2)/4$ - cross section tube area.

7. According to another aspect of the present invention, a tubular member is selected for suitability for expansion on a basis comprising use of an expandability coefficient determined pursuant to a stress-strain test using axial loading in combination with one or more physical properties of the tubular member selected from a group of properties comprising stress-strain properties in one or more directional orientations of the material, Charpy V-notch impact value in one or more directional orientations of the material, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness.

1/5

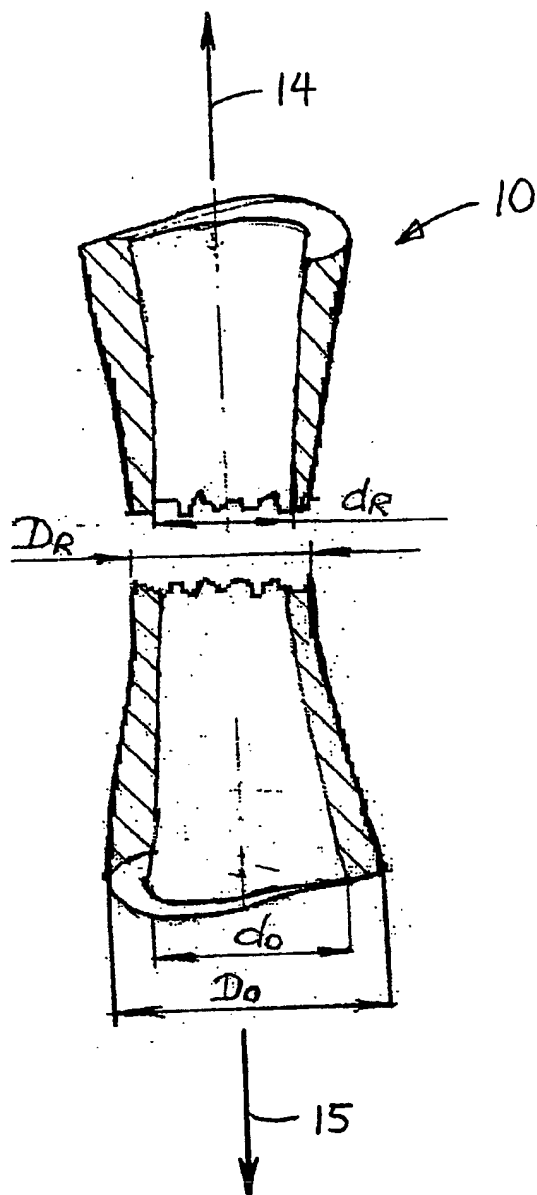


FIG. 1

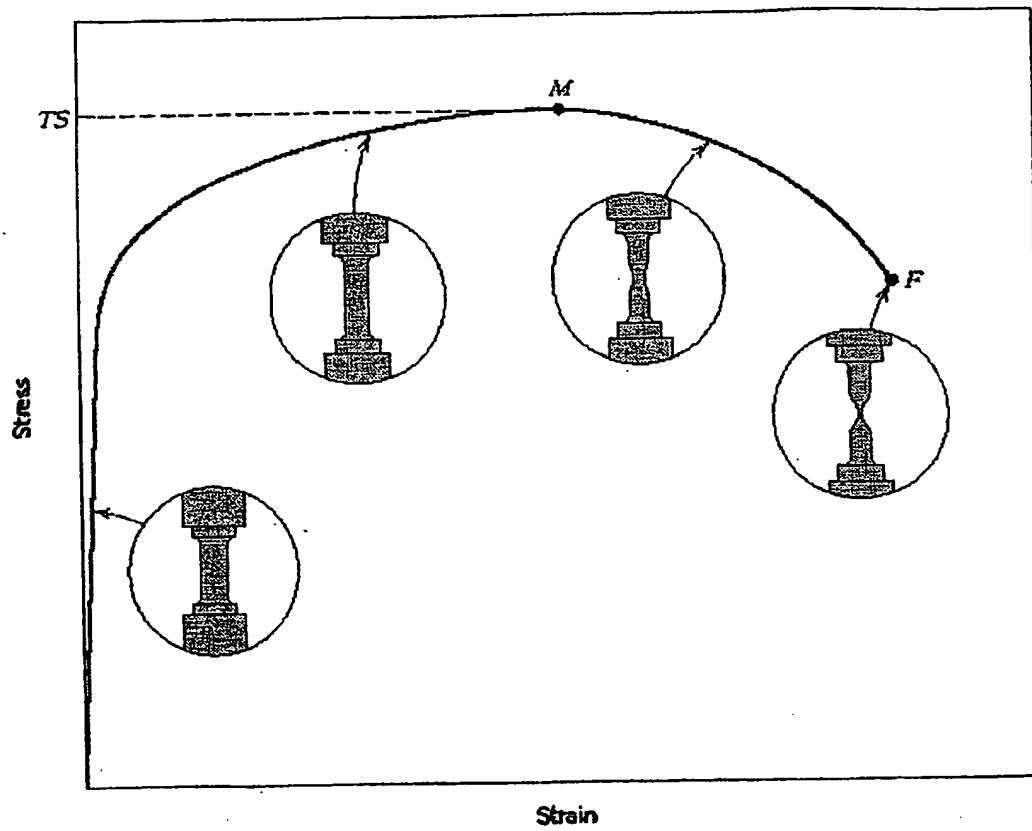


FIG. 2

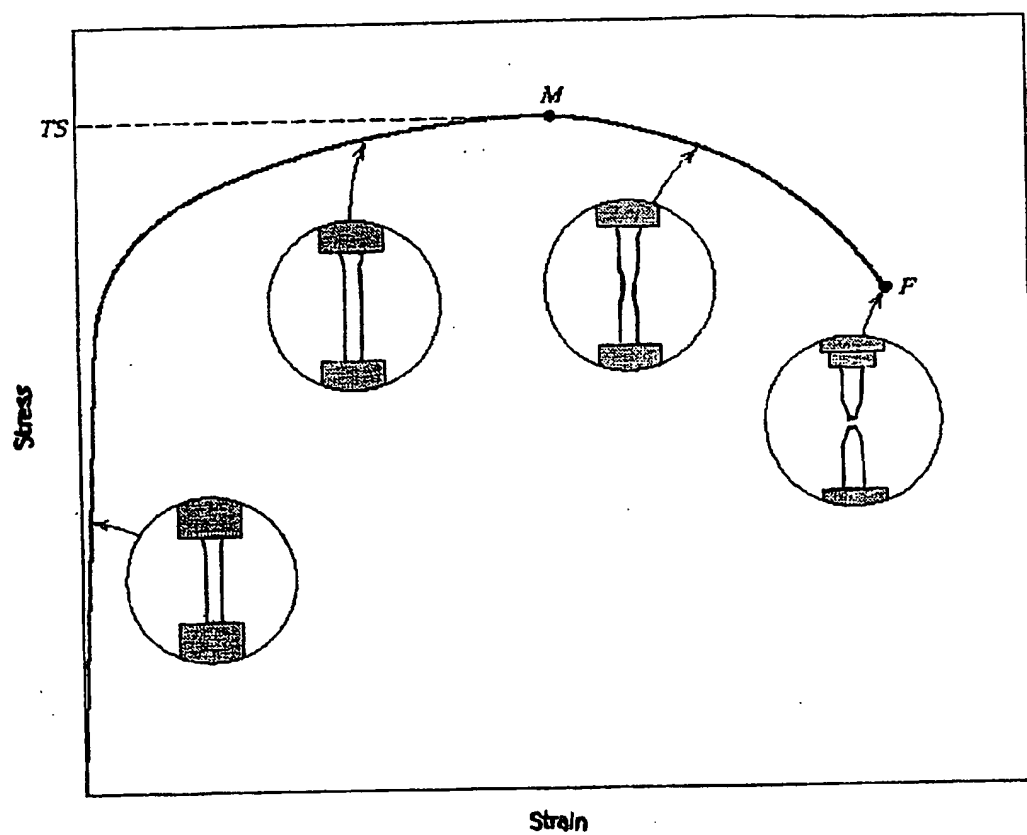


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/25667

A. CLASSIFICATION OF SUBJECT MATTERIPC(7) : G01N 3/08,
US CL : 73/821, 826, 818

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/821, 826, 818

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
East text searchElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPAT, US-PGPub, EPO, JPO, Derwent, IBM_TDP**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 5,134,891 A (CANEVET et al.) 4 August 1992 (4.08.1992), Col. 1, lines 15-26, Col. 2, lines 5-21, Figure 1.	1-2,4-5,7 ----- 3,6
E	US 6,672,759 B2 (FEGER) 6 January 2004 (6.01.2004), Abstract, Col. 9, lines 25-41.	1-7

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

09 January 2004 (09.01.2004)

Date of mailing of the international search report

26 FEB 2004

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
Facsimile No. (703) 305-3230

Authorized officer

Edward Lefkowitz

Telephone No. (703)308-0956

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
1 April 2004 (01.04.2004)

PCT

(10) International Publication Number
WO 2004/027392 A1

(51) International Patent Classification⁷: **G01N 3/08**

(US). RING, Lev [US/US]; 14126 Heatherhill Place, Houston, TX 77077 (US).

(21) International Application Number:
PCT/US2003/025667

(74) Agents: MATTINGLY, Todd et al.; Haynes and Boone, LLP, Suite 4300, 1000 Louisiana Street, Houston, TX 77002-5012 (US).

(22) International Filing Date: 18 August 2003 (18.08.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/412,653 20 September 2002 (20.09.2002) US

(81) Designated States (*national*): AE, AG, AI, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(71) Applicant (*for all designated States except US*): ENVENTURE GLOBAL TECHNOLOGY [US/US]; 16200 A Park Row, Houston, TX 77084 (US).

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

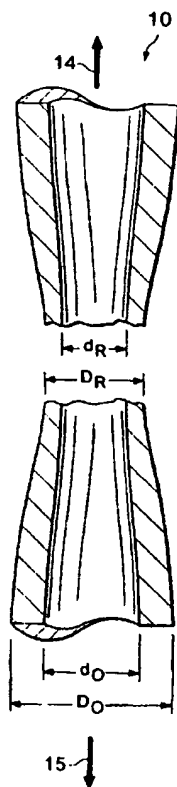
(72) Inventors; and

(75) Inventors/Applicants (*for US only*): SHUSTER, Mark [US/US]; 19115 Prospect Ridge Lane, Houston, TX 77094

[Continued on next page]

(54) Title: PIPE FORMABILITY EVALUATION FOR EXPANDABLE TUBULARS

(57) Abstract: A method of testing a tubular member (10) and selecting tubular members for suitability for expansion by subjecting a representative sample the tubular member to axial loading (14, 15), stretching at least a portion of the tubular member through elastic deformation, plastic yield and to ultimate yield, and based upon changes in length and area calculating an expandability coefficient indicative of expandability of the tubular members (10) and selecting tubular members (10) with relatively high coefficients indicative of good expandability.



WO 2004/027392 A1

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1

— with amended claims

Date of publication of the amended claims: 10 June 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

— *with international search report*

AMENDED CLAIMS

[received by the International Bureau on 21 April 2004 (21.04.04);
claims 1-7 amended, claims 8-35 added]

1. A method of testing a tubular member for suitability for radial expansion and plastic deformation comprising: subjecting at least a portion of the tubular member to axial loading, stretching at least a portion of the tubular member through the elastic deformation, plastic yield and to ultimate yield, and calculating an expandability coefficient f .
2. The method of claim 1, wherein subjecting the at least a portion of the tubular member to axial loading comprises subjecting the entire tubular member to axial loading.
3. The method of claim 1, wherein the step of calculating an expandability coefficient comprises calculating the expandability coefficient using the following formula :

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{l_o b_o}} \quad \text{[Equation 1]}$$

where,

f - expandability coefficient;

b_o & b_k - initial and final tube cross-sectional area (inch²);

L_o & L_k - initial and final tube length (inch);

$b = (D^2 - d^2)/4$ - cross section tube area;

D = tube outside diameter; and

d = tube inside diameter.

4. A method of selecting tubular members for suitability for radial expansion and plastic deformation comprising subjecting at least a portion of a representative sample of tubular members to axial loading, stretching at least a portion of the tubular members through the elastic deformation, plastic yield and to ultimate yield, and calculating an expandability coefficient f , and choosing such tubular members for which the sample provided a desirable coefficient of expandability above a value of 1.
5. The method of claim 4, wherein subjecting the at least a portion of a representative sample of tubular members to axial loading comprises subjecting the entire length of at least one of the tubular members to axial loading.
6. The method of claim 4, wherein the step of calculating an expandability coefficient comprises

calculating the expandability coefficient using the following formula:

$$f = \frac{\ln \frac{b_a}{b_k}}{\ln \frac{L_k b_k}{l_o b_o}} \quad [\text{Equation 1}]$$

where,

f - expandability coefficient;

b_o & b_k - initial and final tube cross sectional area (in²);

L_o & L_k - initial and final tube length (inch);

$b = (D^2 - d^2)/4$ - cross section tube area;

D = tube outside diameter; and

d = tube inside diameter.

7. A method of selecting a tubular member for suitability for radial expansion and plastic deformation comprising using an expandability coefficient determined pursuant to a stress-strain test using axial loading in combination with one or more physical properties of the tubular member selected from a group of properties comprising stress-strain properties in one or more directional orientations of the material, Charpy V-notch impact value in one or more directional orientations of the material, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness.

8. A system for testing a tubular member for suitability for radial expansion and plastic deformation comprising:

means for subjecting at least a portion of the tubular member to axial loading,

means for stretching at least a portion of the tubular member through the elastic deformation, plastic yield and to ultimate yield, and

means for calculating an expandability coefficient f .

9. The system of claim 8, wherein means for subjecting the at least a portion of the tubular member to axial loading comprises means for subjecting the entire tubular member to axial loading.

10. The system of claim 8, wherein means for calculating an expandability coefficient comprises calculating the expandability coefficient using the following formula:

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{l_o b_o}}$$

where,

f - expandability coefficient;

b_o & b_k - initial and final tube cross sectional area (inch²);

L_o & L_k - initial and final tube length (inch);

$b = (D^2 - d^2)/4$ - cross section tube area;

D = tube outside diameter; and

d = tube inside diameter.

11. A system for selecting tubular members for suitability for radial expansion and plastic deformation comprising:

means for subjecting at least a portion of a representative sample of tubular members to axial loading,

means for stretching at least a portion of the tubular members through the elastic deformation, plastic yield and to ultimate yield, and

means for calculating an expandability coefficient f , and choosing such tubular members for which the sample provided a desirable coefficient of expandability above a value of 1.

12. The system of claim 11, wherein means for subjecting the at least a portion of a representative sample of tubular members to axial loading comprises means for subjecting the entire length of at least one of the tubular members to axial loading.

13. The system of claim 11, wherein means for calculating an expandability coefficient comprises means for calculating the expandability coefficient using the following formula:

$$f = \frac{\ln \frac{b_o}{b_k}}{\ln \frac{L_k b_k}{l_o b_o}}$$

where,

f - expandability coefficient;

b_o & b_k - initial and final tube cross sectional area (inch²);

L_o & L_k - initial and final tube length (inch);

$b = (D^2 - d^2)/4$ - cross section tube area;

D = tube outside diameter; and

d = tube inside diameter.

14. A system for selecting a tubular member for suitability for radial expansion and plastic deformation comprising:

means for conducting a stress-strain test on the tubular member;

means for calculating an expandability coefficient determined pursuant to the stress-strain test;

and

means for selecting the tubular member as a function of the expandability coefficient and one or more physical properties of the tubular member selected from a group of properties comprising stress-strain properties in one or more directional orientations of the material, Charpy V-notch impact value in one or more directional orientations of the material, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness.

15. The method of claim 1, further comprising:

selecting the tubular member for radial expansion and plastic deformation if the expandability coefficient is greater than or equal to a predetermined value.

16. The method of claim 15, further comprising:

radially expanding and plastically deforming the selected tubular member.

17. The method of claim 4, further comprising:

radially expanding and plastically deforming one or more of the selected tubular members.

18. The method of claim 7, further comprising:

radially expanding and plastically deforming the selected tubular members.

19. A method of selecting tubular members for radial expansion and plastic deformation, comprising:

characterizing one or more anisotropic characteristics of the tubular members.

20. The method of claim 19, wherein at least one of the anisotropic characteristics comprises a measurement of the plastic anisotropy for the tubular members.

21. A system of selecting tubular members for radial expansion and plastic deformation, comprising:

means for characterizing one or more anisotropic characteristics of the tubular members; and
means for radially expanding and plastically deforming one or more selected tubular members.

22. The system of claim 21, wherein at least one of the anisotropic characteristics comprises a measurement of the plastic anisotropy for the tubular members.

23. The system of claim 21, wherein the selected tubular members comprise a plastic anisotropy measurement equal to a predetermined value.

24. A tubular member, comprising:
a plasticity characteristic that is anisotropic.

25. A system for radially expanding and plastically deforming a tubular member, comprising:
means for selecting tubular members suitable for radial expansion and plastic deformation; and
means for radially expanding and plastically deforming the tubular member.

26. The system of claim 25, wherein tubular members suitable for radial expansion and plastic deformation comprise a plasticity characteristic that is anisotropic.

27. The method of claim 1, further comprising:
selecting a tubular member for radial expansion and plastic deformation as function of the calculated formability coefficient.

28. The method of claim 1, further comprising:
selecting a tubular member for radial expansion and plastic deformation as function of the calculated formability coefficient and one or more of the following:
stress-strain properties in one or more directional orientations, Charpy V-notch impact value in one or more directional orientations, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness.

29. A method of selecting tubular members suitable for radial expansion and plastic deformation, comprising:
selecting a tubular member for radial expansion and plastic deformation as function of formability anisotropy.

30. A method of selecting tubular members suitable for radial expansion and plastic deformation,

comprising:

selecting a tubular member for radial expansion and plastic deformation as function of formability anisotropy and one or more of the following:

stress-strain properties in one or more directional orientations, Charpy V-notch impact value in one or more directional orientations, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness.

31. A method of radially expanding and plastically deforming tubular members, comprising:

selecting a tubular member for radial expansion and plastic deformation as function of the formability anisotropy for the tubular member; and

radially expanding and plastically deforming the selected tubular member.

32. A method of radially expanding and plastically deforming tubular members, comprising:

selecting a tubular member for radial expansion and plastic deformation as function of the formability anisotropy for the tubular member and one or more of the following:

stress-strain properties in one or more directional orientations, Charpy V-notch impact value in one or more directional orientations, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness;
and

radially expanding and plastically deforming the selected tubular member.

33. A system for radially expanding and plastically deforming tubular members, comprising:

means for selecting a tubular member for radial expansion and plastic deformation as function of the formability anisotropy for the tubular member; and

means for radially expanding and plastically deforming the selected tubular member.

34. A system for radially expanding and plastically deforming tubular members, comprising:

means for selecting a tubular member for radial expansion and plastic deformation as function of the formability anisotropy for the tubular member and one or more of the following:

stress-strain properties in one or more directional orientations, Charpy V-notch impact value in one or more directional orientations, stress rupture burst strength, stress rupture collapse strength, yield strength, strain-hardening exponent (n-value), and hardness;
and

means for radially expanding and plastically deforming the selected tubular member.

35. An apparatus, comprising:

a subterranean formation defining a borehole; and
a radially expanded and plastically deformed tubular member positioned within and coupled to
the borehole;
wherein at least a portion of the tubular member comprises a formability characteristic that is
anisotropic.

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☒ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☒ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☒ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☒ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.